COLD-FORMED STEEL RESEARCH CONSORTIUM

SDII Building Archetype Design v2.0

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SDII
Steel Diaphragm Innovation Initiative

About the authors

S. Torabian is a Research Scientist at Johns Hopkins University and the primary creator of version 2.0 of the Steel Diaphragm Innovation Initiative (SDII) building archetypes. Associate Professor M.R. Eatherton (Virginia Tech University) and Professor W.S. Easterling (Iowa State University) provided primary input on the composite beam design and BRB design. Professor J.F. Hajjar of Northeastern University contributed to the oversight and creation of the archetypes. Professor B.W. Schafer of Johns Hopkins University developed the basic framework for archetype selection, provided background on archetype needs, and contributed to the oversight and creation of the archetypes.

CFSRC Information

The Cold-Formed Steel Research Consortium (CFSRC) is a multi-institute consortium of university researchers dedicated to providing world-leading research that enables structural engineers and manufacturers to realize the full potential of structures utilizing cold-formed steel. More information can be found at www.cfsrc.org. All CFSRC reports are hosted permanently by the Johns Hopkins University library in the DSpace collection: https://jscholarship.library.jhu.edu/handle/1774.2/40427.

SDII Information

The Steel Diaphragm Innovation Initiative (SDII) is a multi-year industry-academic partnership to advance the seismic performance of steel floor and roof diaphragms utilized in steel buildings through better understanding of diaphragm-structure interaction, new design approaches, and new three-dimensional modeling tools that provided enhanced capabilities to designers utilizing steel diaphragms in their building systems. SDII was created through collaboration between the American Iron and Steel Institute and the American Institute of Steel Construction with contributions from the Steel Deck Institute, the Metal Building Manufacturers Association, and the Steel Joist Institute in partnership with the Cold-Formed Steel Research Consortium; including, researchers from Johns Hopkins University, Virginia Tech, Northeastern University, and Walter P Moore.

Acknowledgements

Other members of the SDII team contributed to the completion of the building archetypes; particularly Gengrui Wei (Virginia Tech) and Hamid Foroughi (Johns Hopkins). This work is part of SDII which is managed by CFSRC. In addition, this material is based upon work supported by the National Science Foundation under Grant No. CMMI-1562669: NEESR-CR: Transforming Building Structural Resilience through Innovation in Steel Diaphragms. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or other sponsors.

Abstract

Building archetypes are fundamental to exploring and demonstrating the seismic behavior of modern structures. No suitable archetypes or prototypes exist in the open literature that focus on steel deck diaphragms for conventional steel buildings. Three dimensional building analysis, with meaningful contributions from the diaphragm in terms of behavior, has not formed the basis for modern seismic standards in steel at this time. The objectives for the SDII building archetypes include the following. Develop a series of 3D steel-framed archetype buildings that explore and document the design of horizontal lateral force resisting systems (LFRSs) with steel deck-based diaphragms as well as vertical LFRSs and the inter-relationship between the two. Provide a series of buildings that form a common basis of comparison for diaphragms in steel-framed buildings much the same way the SAC buildings did for the vertical LFRS. Explicitly explore the impact of the ASCE 7-16 standard, and ASCE 7-16 alternate diaphragm design with: R_s=1, R_s=2 for steel deck with fill and 2.5 for bare steel deck, and R_s=3 in designs. Inform areas for needed experimentation, and create targets for advancing nonlinear analysis within the full SDII effort.

Version 2.0 of this archetype effort includes complete three-dimensional building designs for 1, 4, 8, and 12 story buildings using either Buckling Restrained Brace Frames (BRBFs) or Steel Concentric Braced Frames (SCBFs). For each design spreadsheets, SAP structural models, and summary slide decks are provided. These archetype designs are being utilized by the SDII project to assess the seismic performance of typical steel buildings.

1 Brief Overview of SDII Building Archetypes v2.0

[The following is excerpted and then adapted from the Steel Diaphragm Innovation Initiative (SDII) Year 4 Final Report. Readers interested in the full report should contact the project PI: Ben Schafer. Release of the report is contingent upon agreement from the sponsors.]

To date in the SDII project, the designed archetypes have been used in: (1) nonlinear time history analysis of 1, 4, 8, and 12 stories Buckling Restrained Braced Frames (BRBFs) and Special Concentrically Braced Frames (SCBFs) in OpenSees including nonlinear diaphragm behavior; (2) selecting the diaphragm details including thickness, steel deck, and headed shear studs in the currently ongoing testing programs; and (3) more in-depth diaphragm behavior evaluations at different R_s factors and proposing initial design recommendations.

Table 1. Status of formal SDII archetype designs of the multi-story diaphragm concentric steel building archetypes

Multi-story steel building archetype typology						
		Reduced order	**stories**			
hLFRS	**vLFRS**	**(Opensees) modeling**	**1**	**4**	**8**	**12**
Steel Deck+LWC	BRBF	VT	designed	designed	designed	designed
	OCBF	JHU				
	SCBF	JHU	designed	designed	designed	designed
	OMF	TBD				
	SMF	TBD				
Steel Deck+LWC+ **Irregular Diaphragms**	BRBF	VT				
	OCBF	JHU				
	SCBF	JHU				
	OMF	TBD				
	SMF	TBD				
Dsteel deck + LWC with Fuses	BRBF	TBD				
	OCBF	TBD				
	SCBF	TBD				
	OMF	TBD				
	SMF	TBD				

indicates that structure would not be code compliant

indicates primary area of work for the team, Completed Summer 2019

indicates secondary area of work for the team, Fall 2019

hLFRS=horizontal Lateral Force Resisting System

vLFRS=vertical Lateral Force Resisting System

LWC=Light Weight Concrete

SCBF= Special Concentrically Braced Frame

NWC=Normal Weight Conceret

OMF=Ordinary Moment Frame

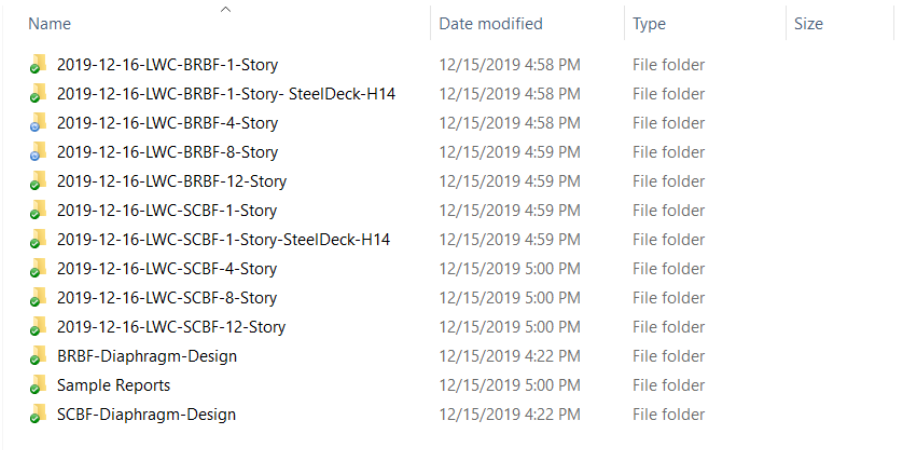
BRB= Buckling Restrained Braced Frame

SMF=Special Moment Frame

OCBF=Ordinary Concentrically Braced Frame

Table 1 summarizes the status of formal SDII archetype designs at the half-way point of year 4 in terms of horizontal systems (hLFRSs) combined with different vertical systems (vLFRSs) and the number of stories. Together the summary set of drawings, spreadsheets, SAP 2000 models and background narrative of all archetype building including 1, 4, 8, and 12 stories BRBFs and SCBFs comprise this report.

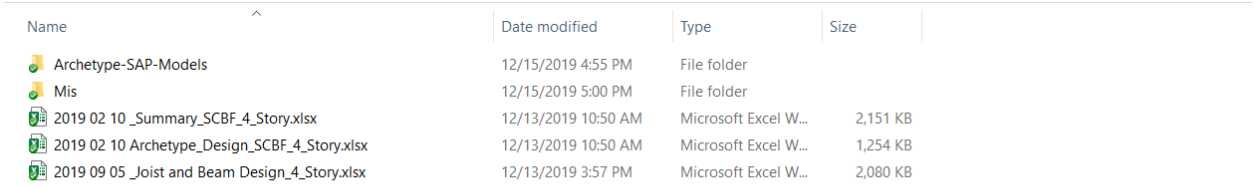
Figure 1 shows the database folder structure for the BRBF and SCBF archetype buildings. The folder names are supposed to be self-explanatory. BRBF and SCBF archetypes buildings 1, 4, 8, and 12 stories are in 10 separate folders. There are two types of one-story building designs, with bare deck, and with composite deck roof. All composite-deck designs were designed with light-weight concrete fill.



Name	Date modified	Type	Size
2019-12-16-LWC-BRBF-1-Story	12/15/2019 4:58 PM	File folder	
2019-12-16-LWC-BRBF-1-Story- SteelDeck-H14	12/15/2019 4:58 PM	File folder	
2019-12-16-LWC-BRBF-4-Story	12/15/2019 4:58 PM	File folder	
2019-12-16-LWC-BRBF-8-Story	12/15/2019 4:59 PM	File folder	
2019-12-16-LWC-BRBF-12-Story	12/15/2019 4:59 PM	File folder	
2019-12-16-LWC-SCBF-1-Story	12/15/2019 4:59 PM	File folder	
2019-12-16-LWC-SCBF-1-Story-SteelDeck-H14	12/15/2019 4:59 PM	File folder	
2019-12-16-LWC-SCBF-4-Story	12/15/2019 5:00 PM	File folder	
2019-12-16-LWC-SCBF-8-Story	12/15/2019 5:00 PM	File folder	
2019-12-16-LWC-SCBF-12-Story	12/15/2019 5:00 PM	File folder	
BRBF-Diaphragm-Design	12/15/2019 4:22 PM	File folder	
Sample Reports	12/15/2019 5:00 PM	File folder	
SCBF-Diaphragm-Design	12/15/2019 4:22 PM	File folder	

Figure 1 SDII building archetype design data structure

Since the archetypes are diaphragm focused, the diaphragm design summary for BRBFs and SCBFs are summarized in spreadsheets under "BRBF-Diaphragm-Design" and "SCBF-Diaphragm-Design" folders. Some sample design reports are provided in the "Sample Reports" folder. The sample reports are providing the design narrative for both BRBFs and SCBFs vertical lateral force resisting systems and diaphragms.



Name	Date modified	Type	Size
Archetype-SAP-Models	12/15/2019 4:55 PM	File folder	
Mis	12/15/2019 5:00 PM	File folder	
2019 02 10 _Summary_SCBF_4_Story.xlsx	12/13/2019 10:50 AM	Microsoft Excel W...	2,151 KB
2019 02 10 Archetype_Design_SCBF_4_Story.xlsx	12/13/2019 10:50 AM	Microsoft Excel W...	1,254 KB
2019 09 05 _Joist and Beam Design_4_Story.xlsx	12/13/2019 3:57 PM	Microsoft Excel W...	2,080 KB

Figure 2 Sample file structure in each archetype folder

Figure 2 shows the file structure in each archetype folder. There are three main design spreadsheets for each archetype building as follows:

"[Date]_Archetype_n_Story.xlsx" is a spreadsheet used to calculate seismic forces for the vertical and horizontal lateral force resisting systems. Vertical and horizontal distribution of the seismic forces have been provided, and the demands for chords and collectors were calculated. Rebars were designed for diaphragm chord and collectors when the perimeter steel beams were not used as chords and collectors.

"[Date]_Joist and Beam design_n_Story.xlsx" is a spreadsheet designing the composite beams and girders for gravity demands, as well as gravity plus axial demands from diaphragms. The composite members (typically chord and collectors) were designed as wide-flanged steel beams connected to the concrete-filled steel decks via steel headed shear studs. The chords and collectors were designed as composite beam-columns, where the flexural capacity was calculated as a composite member, but the axial capacity was calculated as a steel-only member with

continuous lateral support in minor axis bending. The design summary for the gravity demands and for the chord and collector demands were summarized in the first two sheets of the file.

"[Date]_Summary_[Frame type]_n_Story.xlsx" is a spreadsheet summarizing the column sizes, brace sizes, chord and collectors and braced-bay beam sizes, lateral drift checks, torsional amplification factors, second-order effects, width-to-thickness ratios checks for columns of the braced-bay, beams of the braced-bay, and chord and collectors.

Archetype-SAP-Models is a folder typically contains three different SAP2000-19 ".sdb" files, as follows:

"[Frame type]_n_Story.sdb" is a SAP2000-19 file used to check lateral drifts, design gravity columns, design non-composite beams, design braces, and check braced-bay columns for amplified forces.

[Frame type]_n_Story_Ultimate is the SAP2000-19 file used to check braced-bay columns for ultimate forces, and design braced-bay beams for axial demands and gravity bending moments. This model has special boundary conditions and loading to make ultimate forces in the braces and reflect the effects on the other members. Accordingly, this model cannot be used independently to design the structure.

[Frame type]_n_Story_Chord and Collectors is a SAP2000-19 file similar to the "[Frame type]_n_Story.sdb", but the chord and collector member sizes are updated to the chord and collectors designed in "[Date]_Joist and Beam design_n_Story.xlsx." Additionally, the braced bay beam and collectors have been updated to include the members designed in [Frame type]_n_Story_Ultimate. Notably, since the archetype diaphragms have been designed for four levels of diaphragm forces, namely, standard, R_s=1, R_s=2 for composite & R_s=2.5 for bare decks, and R_s=3, the size of chord and collector in this file are just for the standard design and the rest of the design information should be extracted from the spreadsheets.

For additional information on the building archetypes, please contact the primary author: Shahab Torabian, or the project PI: Ben Schafer.